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On the electrode sheath voltage in high-pressure argon, xenon and mercury discharges

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The electrode sheath voltage and the electrical field strength are measured in high-pressure argon, xenon and mercury discharges. There are significant differences in the shape of the ESV of mercury discharges compared with the rare gases.

1. Motivation

High-pressure discharge (HID) lamps have a widespread application in lighting because of their high luminous efficacy. A main problem in the operation of such lamps is a shortening of the lamp life due to a blackening of the lamp wall. The deposited material comes from the erosion of the electrodes and can also lead to the destruction of the electrode. The processes in the plasma sheaths near the electrodes are responsible for heating and the undesirable erosion of the electrodes.
The electrode design and the operating conditions are decisive for the properties of HID lamps. For instance, the power loss in the sheath near the electrodes is not negligible. This is true especially for low-power lamps. The corresponding electrode sheath voltage (ESV) is strongly influenced by the electrode material, the electrode design and the plasma composition. To reveal this influence partially, the ESV is measured in high-pressure argon, xenon and mercury discharges.

2. Experiment

The experiments in Ar and Xe are performed in the model lamp developed in Bochum [1]. Fig. 1 shows the schematic view of the experimental set-up. The discharge tube is made of fused silica ($\varnothing_i$ = 9 mm). Electrode holders are inserted into the ends of the discharge tube and contain the tungsten electrodes ($\varnothing$ = 0.5 – 1 mm, l = 13 mm).
The electrode holders can be moved in the tube by stepping motors and therefore the electrode distance can be varied during operation. The arc length was varied between 1 and 30 mm. The tube was carefully evacuated before the measurements and then filled with argon or xenon at pressures between 1 and 3 bar.
For determining the electric field strength and the ESV in discharges, the used method consists of a voltage measurement at discharges with different lengths but with otherwise identical properties of the plasma column. The electric field strength was then derived from the slope in a plot showing voltage versus gap length. From the same graph, the ESV was obtained by extrapolation to zero for the electrode gap. The underlying assumption is that the arc voltage U_{arc} is composed of the column voltage (field strength E times gap length l) and the ESV (U_{A+C}):

$$U_{arc} = E \times l + U_{A+C}. \qquad (1)$$

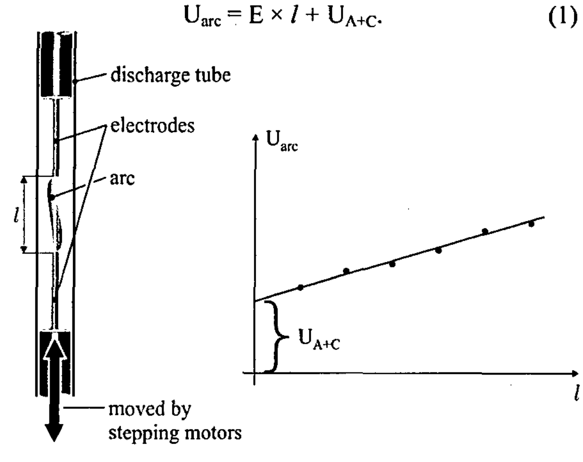

Fig. 1: Schematic view of the experimental set-up for the determination of the electrical field strength and ESV.

For the experiments in Hg we used lamps with different electrode-gap lengths but with otherwise identical geometric and filling conditions for obtaining a very similar arc plasma [2, 3]. The lamps are operated vertically, have an inner diameter of 16 mm and electrode gaps between 28 and 60 mm. The thoriated tungsten electrodes have a diameter of 0.7 mm and are surrounded by a tungsten coil.
The similarity was checked by determining plasma temperature and pressure from spectroscopic measurements of the Hg lines 546 nm and 577/579 nm and the wall temperature with a pyrometer (Varioscan, Jenoptik).
All discharges were operated with a 50 Hz sinusoidal current delivered by a current amplifier (FM1295, Feucht).
Simultaneously to the spectroscopic measurements pictures of the electrode region are taken with a camera (Flashcam, PCO) to control the position of the arc spot at the electrode surface.

The temperatures along the electrodes were determined by a pyrometer (IS10, impac) in the spectral range from 0.7 to 1.1 μm. The input power from the plasma to the electrodes can be determined from the recorded T-slope.

3. Results

The measured electrode sheath voltage and the electrical field strength for a Xe discharge are shown in figure 2. For a better illustration the sinusoidal current is plotted too. ESV and field strength are time-dependent. After current zero a jump of ESV and field strength is followed by an increase of the values leading to a maximum of the field strength of about 8 V/cm at 1.5 ms followed by a slight decrease until the change of polarity. The ESV has its maximum of 16 V at 2 ms and the following decrease is similar to that of the electric field strength.

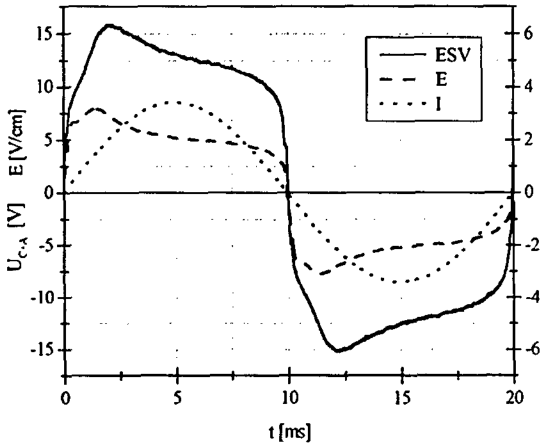

Fig. 2: Current, ESV and field strength of a Xe discharge (2 bar, tungsten electrode diameter 0.5 mm).

Although the operating conditions are only similar but not identical for all discharges, a typical behaviour for each element can be deduced. In figure 3 the ESV is compared for a discharge in Hg (I_{eff} = 3 A, p = 6 bar, $\varnothing_{El}$ = 0.7 mm), Ar (I_{eff} = 3 A, p = 3 bar, $\varnothing_{El}$ = 0.7 mm) and Xe (I_{eff} = 2.4 A, p = 2 bar, $\varnothing_{El}$ = 0.5 mm). The time dependence of the ESV in mercury is strongly pronounced. After a voltage maximum of 55 V during the rising current which corresponds to re-ignition, the current attains its maximum at a medium voltage and decreases then with initially slightly rising voltage which finally goes to zero. There are, however, two significant differences in the ESV compared with the rare gases:

1. a very pronounced "ignition" peak earlier and much higher than in the rare gases and
2. a remarkable voltage minimum near zero in the first quarter of a half cycle.

This voltage minimum does not appear in a calculated cathode fall for Hg [4]. If we attribute this difference to the anode, it would correspond to a negative anode fall of more than 10 V which occurs around 2 ms after current zero [5].

Neither Xe nor Ar show such a strong time dependence. The ESV curves of the rare gases are more flat and only Ar shows a small dip in the ESV in the beginning of current flow. A similar behaviour can be seen for Hg discharges at 5 kHz [3].

The pronounced "ignition" peak is due to the fact that in the Hg discharge a spot mode occurs at the electrode whereas the rare gases show a diffuse mode in this parameter range. For lower discharge currents in rare gases also a spot mode occurs and the ESV has in that case also a higher ignition peak as in the Hg discharge but no minimum.

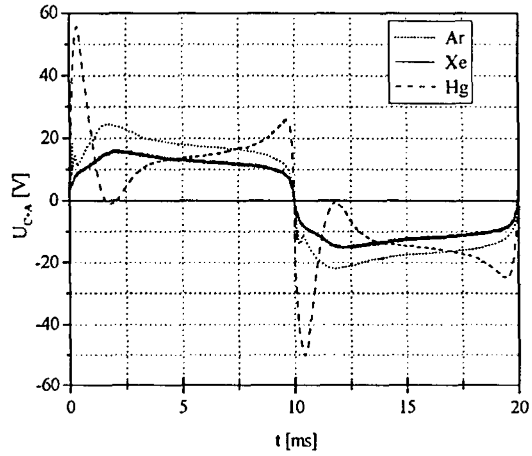

Fig. 3: Comparison of the ESV for a Hg, Xe and Ar discharge.

4. References

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5. Acknowledgement

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